Chapter 7

Assessment of Stormwater Best Management Practice Effectiveness

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Introduction

The use of stormwater practices to control and manage the quality and quantity of urban runoff has become widespread in U.S. and in many other countries. As a group they have been labeled as best management practices or BMPs. Current literature describes a variety of techniques to reduce pollutants found in separate urban stormwater runoff (that is, not CSS). Many of these same practices can also be applied for areas served by CSS to reduce the frequency of combined sewer overflows (CSOs) during wet weather and to enhance quality of the CSOs when they do occur.

Structural BMPs are designed to function without human intervention at the time wet weather flow is occurring, thus they are expected to function unattended during a storm and to provide passive treatment. Nonstructural BMPs as a group are a set of practices and institutional arrangements, both with the intent of instituting good housekeeping measures that reduce or prevent pollutant deposition on the urban landscape.

Much is known about the technology behind these practices, much is still emerging and much remains yet to be learned. Currently many of these controls are used without full understanding of their limitations and their effectiveness under field (i.e., real world) conditions, as opposed to regulatory expectations or academic predictions or beliefs. In addition, the uncertainties in the state of practice associated with structural BMP selection, design, construction and use are further complicated by the stochastic nature of stormwater runoff and its variability with location and climate. Where one city may experience six months of gentle, long-duration rains; another will experience many convective and frontal rainstorms followed by severe winter snows that melt in the spring; while still another will experience few, mostly convective storms. At the same time, examination of precipitation records throughout the U.S. reveals that the majority of individual storms are relatively small, often producing less precipitation and runoff than used in the design of traditional storm drainage networks.

A number of structural and non-structural BMPs are discussed in this chapter focusing on their effectiveness in removing pollutants and in mitigating flow rates. BMP effectiveness in addressing some of the stipulated impacts of urban runoff on receiving water systems is also discussed.

After much literature review Roesner, Urbonas and Sonnen (1989) concluded the following:

> ***Among all these devices the most promising and best understood are detention and extended detention basins and ponds. Less reliable in terms of predicting performance, but showing promise, are sand filter beds, wetlands, infiltration basins, and percolation basins. All of the latter appear to be in their infancy and lack the necessary long-term field testing that would provide data for the development of sound design practices.***

Information published since 1989 has expanded very little understanding of structural BMPs and their performance. However, urban water professionals may be on a verge of a breakthrough in identifying and possibly quantifying some of the linkages between the urban runoff processes and its effects on various aspects of receiving systems. This should lead to a better understanding of how and why various types of BMPs may be able to moderate some of the effects on receiving systems. It is unlikely, however, that BMPs and other techniques will be able to eliminate all of the effects on receiving systems that are caused by the growth in population world wide, especially the population growth of urban areas.

Objectives in the Use of Best Management Practices for Stormwater Quality Management

The comprehensive -- quantity and quality -- approach to stormwater management is relatively new. Prior to the late 1960's the primary goal was to rapidly drain municipal streets and to convey this drainage to the nearest natural waterway. This practice evolved into the use of detention when the municipal engineers began to recognize that the cost of urban drainage systems became prohibitive as more and more of the watershed urbanized. Also, some began to recognize the deleterious effects that uncontrolled urban drainage had on the stability of the receiving stream. One of the first states to require the control of smaller runoff events, namely the peak runoff rate from the two-year design storm, was Maryland. In the late 1970's, Maryland was also the first to require stormwater quality BMPs, including stormwater infiltration. As a result, it and some of the other states like Florida became early field test beds for these facilities. Although much has yet to be learned before engineers can design for a specific performance, BMP knowledge is evolving. Currently, the design professional and the planner have to think in terms of how to best manage stormwater runoff in order to limit damage to downstream properties, reduce stream erosion, limit the effects on the flora and fauna of the receiving streams and integrate stormwater systems into the community.

As the field of stormwater management expanded in its scope, water quality became an increasingly important consideration at many locations in the U.S. Structural BMPs cannot do the job alone without the cooperation and participation of the public. Prevention and good housekeeping became two operative words and practices. They are now considered as important as the use of structural BMPs and may be the only affordable approaches for much of the currently urbanized landscape.

Figure 7-1 conceptually summarizes four basic objectives for stormwater quality management. The first objective includes the concepts of prevention and load reduction. This is followed by the use of other non-structural and structural measures.

The following four objectives provide an integrated and balanced approach to help mitigate the changes in stormwater runoff flows that occur as land urbanizes and to help mitigate the impacts of stormwater quality on receiving systems:

1. Prevention: Practices that prevent the deposition of pollutants on the urban landscape including changes in the products that, when improperly used or accidentally spilled, deposit pollutants on the urban landscape and changes in how the public uses and disposes of these types of products.

2. Source control: Preventing pollutants from coming into contact with precipitation and stormwater runoff.

3. Source disposal and treatment: Reduction in the volume and/or rate of surface runoff and in the associated constituent loads or concentrations at, or near their source.

4. Follow-up treatment: Interception of runoff downstream of all source and on-site controls using structural BMPs to provide follow-up flow management and/or water quality treatment.

Whenever two or more of these objectives are implemented in series within a watershed, they form a treatment train. A long line of discussions among some regulators and stormwater professionals indicates a belief that the implementation of more than one of these objectives in a treatment train fashion (Livingston et al., 1988, Roesner et al. 1991, Schueler et al.,1991, Urbonas and Stahre 1993, WEF & ASCE 1998) will result in better quality stormwater reaching the receiving waters. Whether this is true or not has not been conclusively field tested. Intuitively this assertion makes sense, but whether the use of a set of structural BMPs or the use of more than one of these objectives in various combinations has any significant or measurable mitigation of urban runoff effects on the receiving waters has yet to be answered. Obtaining the answer will require well designed and controlled field studies, with each taking place over a number of years. Nevertheless, each set of practices appears to add to the arsenal of tools that help manage stormwater runoff and its quality. If nothing else, their use probably adds to the quality of urban life and the enjoyment of the receiving waters into which urban runoff drains.

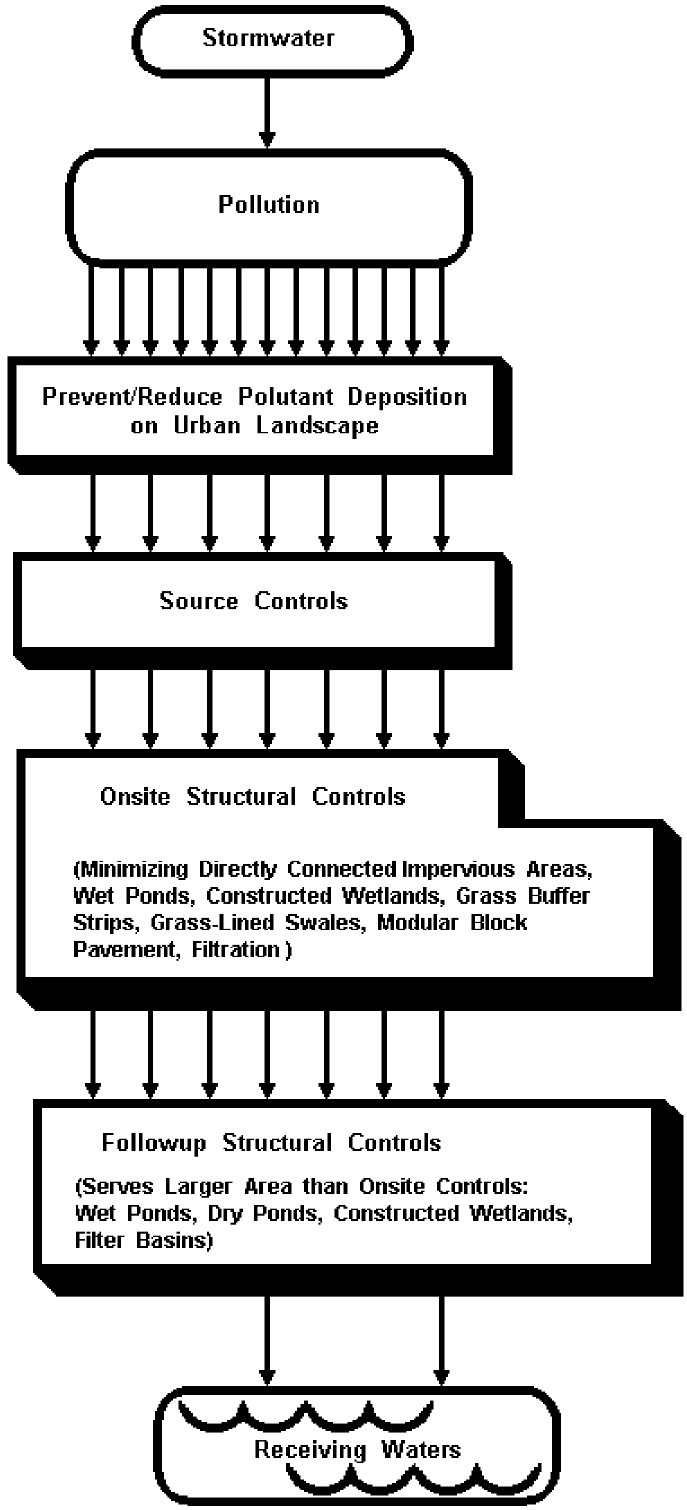

Figure 7-1. BMPs in series to minimize urban stormwater runoff quality impacts (UD&FCD 1992).

Non-Structural Best Management Practices

Non-structural BMPs include a variety of institutional and educational practices that, hopefully, result in behavioral changes which reduce the amount of pollutants entering the stormwater system and, eventually, the receiving waters into which it drains. Some of these non-structural practices deal with the land development and redevelopment process. Others focus on educating the public to modify behavior that contributes to pollutant deposition on urban landscapes. Others search out and disconnect illicit wastewater connections, control accidental spills, and enforce violations of ordinances designed to prevent the deposition of pollutants on the urban landscape and its uncontrolled transport downstream. Among a variety of practices, non-structural BMPs include:

1. Discontinuing or reducing the use of products that have been identified as a problem (e.g., use of phosphorous free or low phosphorous detergents, limiting the application of pesticides, calibrating the application of sand and salt applicators to road surfaces in winter).

2. The adoption and implementation of building and site development codes to encourage or require the installation of structural BMPs for a new development and significant redevelopment projects.

3. Adoption and implementation of site disturbance/erosion control programs.

4. Minimizing the DCIA in new development, including the use of landscaped areas for the discharge of stormwater from impervious surfaces, grass buffers, and roadside swales instead of curb and gutter.

5. Public education on the proper uses and disposal of potential pollutants such as household chemicals, paints, solvents, motor oils, pesticides, herbicides, fertilizers, and antifreeze.

6. Effective street sweeping and leaf pickup and efficient street deicing programs.

7. Detection and elimination of illicit discharges from wastewater lines to separate storm sewers.

8. Enforcement of the operation and maintenance requirements of privately owned stormwater management facilities, including on-site structural BMPs and non-structural programs.

9. Providing the needed operation and maintenance for publicly owned BMPs.

Structural Best Management Practices

Stormwater runoff quality enhancement begins with the avoidance and prevention of pollutant deposition onto the urban landscape (Urbonas and Stahre 1993). It is likely that structural BMPs cannot do the job alone and be fully effective. Structural BMPs need to be viewed as only a supplement to the "good housekeeping measures" being practiced within a community. Once the development and implementation of a non-structural program is in progress, the use of the BMPs discussed in this section can be considered.

Minimized Directly Connected Impervious Area

This practice is listed under the structural BMPs because it can be provided only when land is being developed (i.e., changed from agricultural or an undeveloped state to an urban development) and when significant amounts of older urbanized areas undergo redevelopment. Retrofitting this BMP into developed areas is probably not generally feasible because of the great expense and the physical disruption of neighborhoods and their residents.

Minimizing DCIA relies on the construction of urban streets, parking lots and buildings using a non-traditional template. Figure 7-2 illustrates two hypothetical areas, one using traditional drainage practices and the other the minimal DCIA concept. Instead of elevated landscape islands in a commercial areas, this concept uses landscaped areas that are lower than the adjacent street and parking lot grades to intercept, detain and convey surface runoff. Also, porous pavement parking pads can be used to intercept surface runoff from impervious paved areas. This concept for new land development includes an extensive use of swales, grass buffer strips, porous pavement, and random placements of infiltration basins (infiltration areas) whenever site conditions permit. Not all of the features illustrated in Figure 7-2 are feasible at all sites, nor is this concept feasible for all development sites or land use types. Site conditions such as local geology, soils, groundwater levels, terrain slopes, soil stability, meteorology, land uses and development policies need to be fully evaluated to determine if this practice is feasible.

The intent is to slow down the rate of stormwater runoff and to encourage infiltration. In so doing, surface runoff volumes during small storms can be reduced somewhat for the majority of sites and totally eliminated under most favorable site conditions.

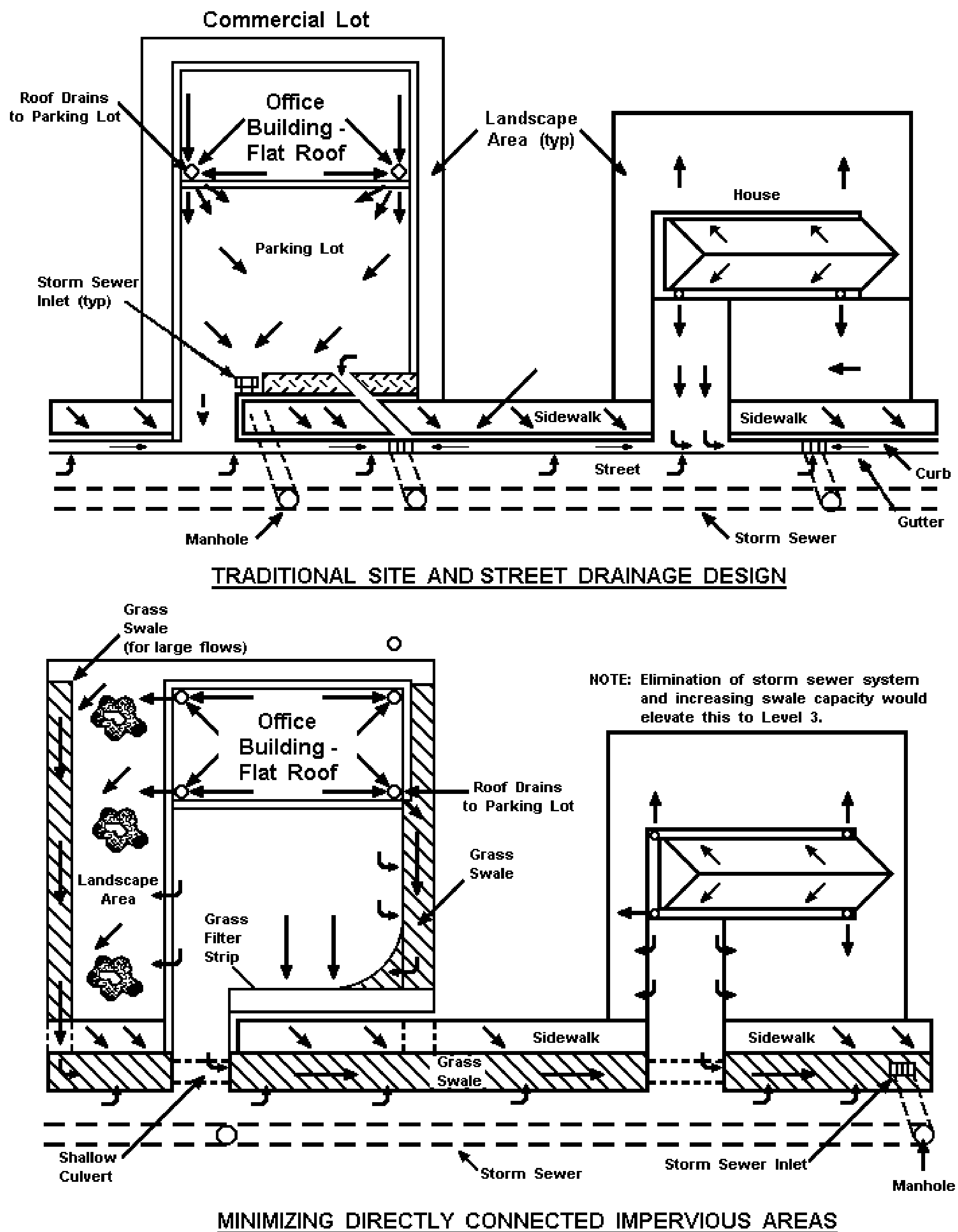

Figure 7-2. Comparing traditional and minimized directly connected impervious area drainage (UD&FCD 1992).

Water Quality Inlets

Water quality inlets are single or multi-chambered underground sediment or sediment and oil separation vaults. Some are simple catch basins with a depressed bottom where the heavier sediments settle before stormwater enters the downstream conveyance system. Others are more complex, equipped with more than one chamber, have lamella plates and/or are designed to separate solids, floatables, oils and greases from water. These type of devices have been in use for years and primarily serve very small tributary catchments.

Infiltration Practices

This group of structural BMPs include swales, grass buffer strips, porous pavement, percolation trenches, and infiltration basins. Water that infiltrates can sometimes drain to the groundwater table. As a result, this practice has to be used with caution and may not be appropriate for sites that have gasoline stations, chemical storage areas and other activities that that can contaminate land surfaces and the groundwater below. Each of these practices is described in more detail as follows:

1. Grass Swale: The slower the flow in a grass swale, the more pollutants will be removed from stormwater through sedimentation and the straining of surface runoff through the vegetative cover. Also, the slower the flow, the more time stormwater has to infiltrate into the ground. The ultimate in slow flow is a swale that acts as a linear detention basin.

2. Grass buffer strip: To remove the heavier sediment particles, a grass buffer strip has to have a flat surface with a healthy turf-forming grass cover. Pollutants are removed from stormwater primarily through sedimentation and the straining of stormwater runoff through the vegetative cover. In arid and semi-arid climates, grass buffer strips need to be irrigated (UD&FCD 1992).

3. Porous Pavement: Porous pavement has been used in the U.S. and Europe since the mid-1970s. It is constructed either of monolithically poured porous asphalt or concrete, or modular concrete paver blocks.

4. Percolation Trench: A percolation trench is a rock filled trench that temporarily stores stormwater and percolates it into the ground. A percolation trench typically serves small impervious tributary areas of two hectares or less.

5. Dry Well: A dry well is a rock filled vertical well that temporarily stores stormwater in order to allow it time to percolate into the ground. It is similar in operation to a percolation trench. Dry wells are sometimes used to penetrate an impermeable layer near the surface to provide a stormwater conduit to a permeable soil layer that lies below it. Dry wells typically serve small impervious tributary areas of two hectares or less.

6. Infiltration Basin: An infiltration basin intercepts and temporarily stores stormwater on its surface, where it eventually infiltrates into the ground. An infiltration basin often serves a small developed catchment, one with less than four hectares of tributary impervious surface.

Filter Basins and Filter Inlets

The use of media filter basins, mostly sand filters, for stormwater quality enhancement was first reported by Wanielista et al. (1981) and Veenhuis et al. (1988). Since then the use of filters has expanded, with most uses reported in the State of Delaware, the Washington DC area, Alexandria, VA and the Austin, TX area (City of Austin 1988, Livingston et al. 1988, Anderson et al. Undated, Chang et al. 1990, Truong et al. 1993, Bell et al. 1996).

Recently, media filters such as peat-sand mix, sand-compost mix and goetextiles have also been tested and proposed for use (Farham and Noonan 1988, Galli 1990, Stewart 1989). An ingenious sand filter inlet has been suggested by Shaver and Baldwin (1991). In most of the suggested filter designs, a detention volume is provided upstream of the filter media. This volume captures the runoff and permits it to flow through the filter at a flow rate compatible with its size and hydraulic conductivity.

Swirl-Type Concentrators

These complex underground vaults are designed to create circular motion within the chamber to encourage sedimentation and the removal of oil and grease. They are also often equipped with trash skimmers and traps. Swirl concentrators are designed to effectively process up to a design flow rate and to by-pass higher flow rates.

Extended Detention Basins

Detention basins hold stormwater temporarily (i.e., detain). They are sometimes called dry detention basins or ponds because they drain out, for the most part, completely after the runoff from a storm ends and then they remain “dry” until the next runoff event begins. The joint use of the terms “dry-pond” is an oxymoron and, for the sake of consistent terminology, the expression detention basin is suggested.

Retention Ponds

Retention ponds have a permanent pool. Some are equipped with a formal surcharge detention volume above this pool. Processes that are known, or are suspected to be at work in a retention pond are sedimentation, flocculation, agglomeration, ion exchange, adsorption, biological uptake through microbial and plant ingestion and eutrophication, remobilization, solution, and physical resuspension of particulates. In the main body of the pond, particulate pollutants are removed by settling and nutrients are removed by phytoplankton, algal and bacterial growth in the water column. Marsh plants around the perimeter of the pond provide the biological media to help remove nutrients and other dissolved constituents and trap small sediment and algae in the water column.

Wetlands

Currently, the use of wetlands as stormwater quality enhancing facilities is an emerging technology. Wetlands can be used as source controls or as follow-up treatment devices. A wetland basin, in essence, is another form of an extended detention basin or a retention pond. As a result, all of the constituent removal processes listed for an extended detention basin and a retention pond should also apply to a wetland basin.

A wetland channel is similar to a grass-lined channel, except it is designed to develop wetland growth on its bottom and is typified by a flat longitudinal slope, wide bottom and slow flow velocities during the two-year and smaller storm runoff events. A wetland channel, to a smaller degree and depending on specific site conditions and design, probably has many of the constituent removal characteristics of a wetland basin.

Stormwater Quality Management Hydrology

Urbonas, Guo and Tucker (1990) observed that capture volume effectiveness in the Denver, CO area reached a point of diminishing returns. This point, referred to by some as the "knee of the curve," was later defined as the point of maximized capture volume (Urbonas and Stahre 1993). Figure 7-3 indicates that this is the point where rapidly diminishing returns begin to occur. Beyond this point the number of events and the total volume of stormwater runoff fully captured during an average year decrease significantly as the detention volume is increased.

Although the number of storms, and their characteristics such as intensity, volume, duration, seasons, and storm separation vary with location, a pattern of diminishing returns was observed by Roesner et al (1991), Guo and Urbonas (1996) Urbonas et al (1996 a), Heaney and Wright (1997) and others. This seems to be the case for all precipitation gauging sites analyzed, regardless of the hydrologic regions in U.S. in which they are located. The other finding was that the maximized capture volume, once determined for a given site, captured 80 to 90% of all runoff events and runoff volumes at the site. This volume was also sufficient to capture the “first flush” of storm runoff during the larger events that exceed the design capture volume.

Table 5.1 in WEF & ASCE (1998) lists the maximized capture volumes at six study sites studied by Roesner et al. (1991) located in different hydrologic regions of U.S. They observed that 1.0 watershed inches (25.4 mm) of storage volume captured more than 90% of all the runoff volume at all six sites and that 0.5 watershed inches (13 mm) of available storage volume captured over 90% of the runoff at the four residential neighborhoods among the six sites.

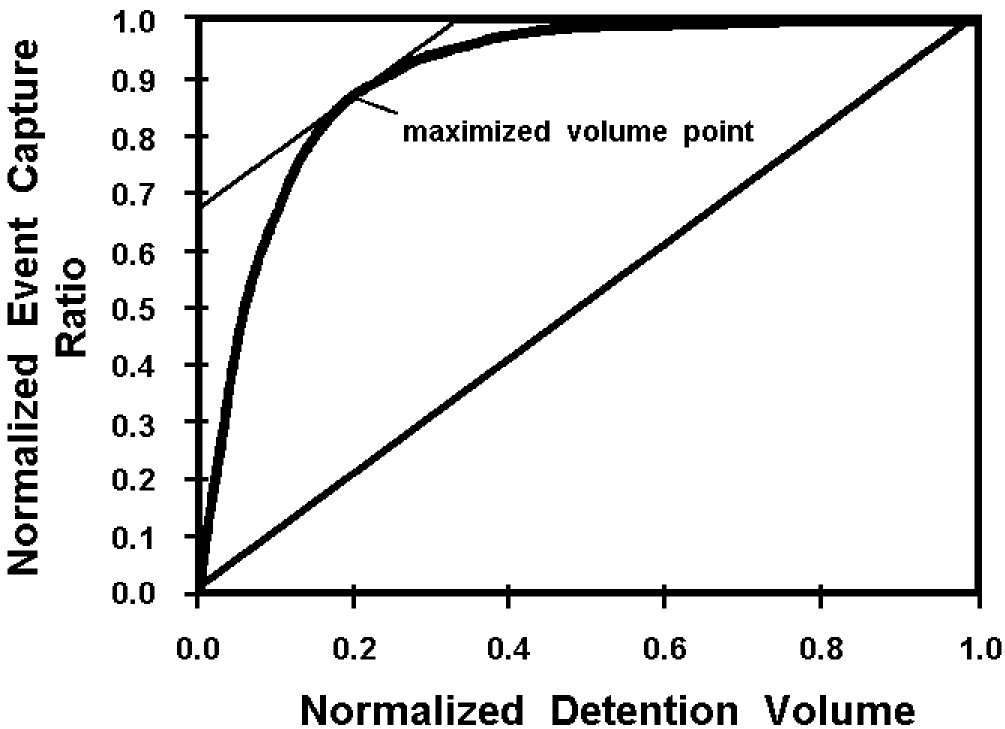

Figure 7-3. Ratio of events captured as a function of the normalized detention volume. (Urbonas et al*.,* 1990).

The finding of a maximized volume point at all rain gauge records studied throughout U.S. prompted Guo and Urbonas (1996) to search for a relationship between the mean runoff producing storm depths reported by Driscoll et al. (1989) and the maximized capture volume. Such a relationship was found in 1993, and was later simplified by Urbonas et al*.* (1996) into a simple linear function. WEF & ASCE (1998) adopted this relationship and recommends its use for simple on-site designs and initial planning efforts.

Grizzard et al*.* (1986), based on laboratory and field studies in the Chesapeake Bay area, suggested that detention basins need to capture the runoff from a mean storm and hold it for an extended period of time to effectively remove pollutants associated with total suspended solids (TSS). They suggested that such a detention basin be equipped with an outlet that released its full volume in 24 hours or more.

This concept was examined using continuous modeling to test the sensitivity of the capture volume size for the Denver area (Urbonas et al. 1990). Table 7-1 summarizes these findings and shows is that the idea of “bigger is better” is not justified for TSS removal by a retention pond equipped with an extended detention surcharge volume above its permanent pool. Field studies at the Shop Creek pond facility in Aurora, CO (Urbonas et al. 1993) produced results consistent with these findings.

The need to focus on TSS removal by BMPs has been recently reinforced by DiToro et al. (1993) and Cerco (1995). They both studied bottom sediment in receiving waters and found that sediment deposits in Chesapeake Bay can have a benthic oxygen uptake. Thus, TSS reduction in stormwater runoff can be the primary reason for selecting and sizing many structural BMPs.

Table 7-1. Sensitivity of the BMP capture volume in Denver, CO (Urbonas et al. 1990).

Capture Volume to Maximized Volume Ratio	Percent of Annual Runoff Volume Captured	Percent of Average Annual TSS Removed
0.7	75	86
1.0	85	88
2.0	94	90

Thus, in order to be effective in the removal of most constituents found in stormwater, structural BMPs need to focus on the frequently occurring smaller events. As a result, detention and retention facilities, wetlands, infiltration facilities, media filters, water quality inlets, swirl concentrators and possibly swales need to be designed to accommodate the runoff volumes and flow rates that result from smaller storm events. It has been recommended that the capture volume for water quality enhancement and for the protection of receiving stream integrity be somewhere between the runoff volume from a mean storm event (Driscoll et al.,1989) and the maximized volume (Urbonas et al. 1990, Hall et al.,1993, Guo and Urbonas 1996). Furthermore, this volume should be released over an extended period of time, namely, somewhere between 12 to 48 hours (Grizzard et al. 1986, Urbonas et al., 1990, Urbonas and Stahre 1993).

Other design considerations, however, come into play when dealing with the removal of nutrients and dissolved constituents. The permanent pool volume of ponds, the volume and the surface area of wetlands and other biochemical dependent BMPs (e.g., peat-sand mix filter) need to be designed and sized on considerations other than only capture volume (Hartigan 1989, Lakatos and Mcnemer 1987, Galli 1990). Nevertheless, even these facilities are likely to benefit from a surcharge capture volume sized as discussed in the preceding.

An Assessment of Best Management Practice Effectiveness

Non-Structural Best Management Practices

Non-structural BMPs rely on human behavioral changes to reduce the amount of pollutants that enter a separate stormwater system, which transports untreated stormwater and the pollutants it contains to receiving waters such as arroyos, gullies, brooks, streams, lakes, estuaries, and reservoirs. As a result, quantifying the amounts of various constituents (some of which may be pollutants) that non-structural practices eliminate from being delivered to these receiving waters is very difficult.

Some of these practices directly affect the types and numbers of structural BMPs that are going to be used as land development and redevelopment takes place. As a surrogate measure, the effectiveness of the structural controls, and the percentage of the total urban landscape within a community or a watershed these controls intercept, can be used to quantify the effectiveness of the regulatory, non-structural practices.

On the other hand, how does one measure the amount of pollutant load that does not reach the receiving systems because of educating the public or a change in behavior? USEPA (1993) goes into much discussion and detail on what to do and how to do it, but does not provide reliable methods for quantifying the effectiveness of non-structural BMPs in reducing pollutant loads reaching the receiving waters of this nation.

The discussion that follows attempts to address some of the issues and questions regarding non-structural BMP effectiveness. It draws on many discussions involving municipal public works and park department officials in Colorado and other states. Some of it interprets and adds to the issues discussed by USEPA (1993). Unfortunately, no field data is known to exist on the effectiveness of many of these practices on reducing the pollutant loads reaching receiving waters. However, several field studies are under way, the most prominent known study being the one in Portland, OR. Hopefully, with sufficient data from well controlled field investigations, some of the outstanding questions will begin to be answered.

Pollutant Source Controls

For this practice to be effective, widespread changes must occur in the use of various potentially polluting products. It is insufficient for a single city or metropolitan area to discontinue the use of a product it believes to pollute its waterways because such a product will be brought in from outside from adjacent communities where it is still being used. For example, requiring that only phosphorous free or low phosphorous detergents be sold will only work if such a ban is state or nation wide.

On the other hand, municipalities and industries can, through proper training and licensing, probably reduce the amount of certain types of pollutants applied to their landscapes. Through changes in the traditional ways some of these institutions handle and apply various materials to the urban landscape in their daily maintenance and operation activities, loads of various materials reaching the surface waters can probably be reduced. For example, proper application of pesticides and herbicides and minimizing their overspray will reduce the amount of these chemicals applied on the vegetated and adjacent impervious surfaces. Also, the calibration of equipment to minimize the rate of salt and other deicing chemicals being applied to road surfaces in winter should also reduce the loads of these chemicals reaching the receiving waters and groundwater when ice and snow melts. Other possible municipal practices that can help reduce pollutant loads reaching the receiving waters could include the licensing and training of pesticide and herbicide applicators; controls on how and where commercial carpet cleaners dispose of their waste water; building codes requiring rain covers over fueling pumps, mechanical maintenance areas, and chemical storage and loading areas; and proper storage and handling of garbage disposal bins at food handling institutions such as restaurants and other commercial and industrial activities.

Intuitively, all of these can reduce the amount of pollutants applied to the urban landscape. However, to what degree these practices actually reduce the amount of various pollutants reaching the receiving waters, or if the quantities being reduced actually make a difference to the water quality of the receiving waters, has yet to be quantified. If only insignificant gains in receiving water are in fact possible, are all or any of these practices remotely cost effective? These questions still need carefully designed field studies to answer. One question that remains is how aggressively should municipalities pursue such non-structural controls and practices before answers about their effectiveness are in. Should the municipalities focus primarily on practices they know work well for the site specific conditions of their community?

Public Education and Citizen Involvement Programs

The goal of public education according to those involved in the field is to modify behavior. That is also the stated goal of US EPA (1993). To be effective, modifications are needed in how a large majority of individuals use and dispose of fertilizers, pesticides, herbicides, crankcase oil, antifreeze, old paint, grass clippings and many other products that contain toxicants, nutrients or oxygen demanding substances. To what degree and in what numbers changes in behavior can be achieved through public education has yet to be answered.

The belief is that the more aggressive the education program, the more effective it should be. This has to be questioned, since there probably is a point of diminishing returns. Where that point is has yet to be determined and will probably be, to one degree or another, a function of the economic, social, ethnic, educational and language makeup of the population being targeted. For public education to work, the target public has to care, or has to be convinced to care. Simple distribution of information through mass media or through written materials is not likely to achieve widespread acceptance of the message or results in terms of water quality improvements.

Walesh (1993, 1997) advocates a proactive public involvement program that goes beyond public education, which tends to be one-way "communication," and instead reaches for public involvement, which constitutes to two-way communication. Guiding principles of these public involvement programs include:

- A public interaction program, or lack thereof, is often the principal reason for the successful implementation of an urban water program or the failure to implement it.

- The success of a public involvement program is determined more by the total number of different "publics" that participate than by the told number of individuals involved.

- Essential to the success of a water management effort is agreement between the public and the water professionals on what problems are to be prevented or mitigated.

In addition to public education and involvement efforts, communities need to have programs in place that make it convenient for the public to dispose of unwanted household products and toxicants. Disposal centers with easy access need to be in place so the public can, in fact, follow through on what is being asked of them.

Street Sweeping, Leaf Pickup and Deicing Programs

Field tests by US EPA (1983) demonstrated that street sweeping reduced by very little the concentrations of constituents reaching receiving waters. It may be possible, however, that strategically scheduled sweepings at key periods of the year can reduce constituent loads available for wash off by stormwater. For example, in the midwest, sweeping in the fall and in late winter months can reduce the leaf litter and street deicing products reaching receiving waters. With current technology, street sweeping is most effective in picking up coarse sediment and litter, thus enhancing the aesthetics of stormwater discharges.

Local Government Rules and Regulations

Well drafted ordinances, rules, regulations and criteria and their enforcement can provide the basis for an effective stormwater management program especially in providing structural BMPs and erosion and sediment control for new land development and redevelopment. Such local ordinances, rules and regulations can help reduce impacts of urban runoff from newly urbanizing lands by providing for and/or requiring:

1. Installation of structural BMPs as land develops or redevelops. This is less expensive than retrofitting structural BMPs later.

2. Enforcement of site disturbance and erosion control programs.

3. Encouragement of the use of minimized DCIA in new development, including the use of landscaped areas, grass buffers, and roadside swales instead of curb, gutter and storm sewer whenever site conditions and land uses permit.

4. Maintenance for publicly owned BMPs.

5. Enforcement of the operation and maintenance of privately owned stormwater management facilities, including on-site structural BMPs and non-structural measures.

Elimination of Illicit Discharges

Untreated wastewater discharged through illicit connections is a public health concern, which justifies efforts to find and eliminate illicit wastewater connections. Illegal dumping, however, because to its covert nature, is extremely difficult to control and soliciting the help of the public to report suspicious or apparently illegal activities may be one way for extending its effectiveness.

Structural Best Management Practices: Design Considerations

Many factors influence the effectiveness of any structural stormwater BMP installation. Although progress has been in understanding how some of these controls perform, selecting, sizing, designing, operating and maintaining effective BMPs for the purpose they are intended to serve is still a challenge. Many BMPs are used without full understanding of their limitations and their effectiveness under field conditions, which often differs from regulatory expectations or modeled predictions. This is particularly the case when addressing the effects of urbanization on the receiving waters.

What is a particular BMP supposed to address? Is it the removal of suspended solids, or is it the removal of dissolved metals or is it the organic matter in the sediment that can settle on the bottom and cause sediment oxygen demand on the water column? Which of these or other “problems” is most important when selecting a single BMP or a group of BMPs? For instance, recent bottom sediment studies reveal that these sediments can have a significant benthic oxygen uptake and may be the cause of oxygen sags and suppression of micro invertebrate populations in the receiving waters (Cerco 1995, DiToro and Fitzpatric 1993). If that is the case, the removal of sediment may be the primary reason for selecting the BMP instead of nutrients that have also been linked to oxygen sags. Or should the selection of the BMP be driven by the need to reduce flow rates and volumes of runoff from urbanizing areas? These and other factors need to be considered in planning for maintenance and/or the restoration, or determining the inability to attain a desired restoration level, and recommending a family of BMPs for use in any given watershed.

Local Climate

As a first step, one needs to consider local climate. If the treatment control relies on a "wet" condition for vegetation and biological processes, the site needs adequate ambient precipitation throughout all seasons. In arid and semi-arid areas, such as the southwest, such treatment controls are not practical unless supplemental water is provided to make up for the evapotranspiration during dry seasons. Thus, when assessing the effectiveness of structural controls, the suitability of the practice for the local climate and meteorology must be considered.

Design Storm

The use of an appropriate design storm to size a facility is probably one of the most important considerations. Often some designers and regulators believe that the bigger the design storm the more effective the control facility will be. That often is far from the truth. Controls designed to improve stormwater quality and to control downstream flow rates need to be matched with the type of facility being used, local hydrology and the receiving system needs. Use of an appropriate design hydrology to design each control facility is assumed in developing the various assessments of BMPs that follow.

Nature of Pollutants

The nature of stormwater pollutants has to be considered when selecting and sizing BMPs. Most BMPs are suited for the reduction in suspended solids and of the dissolved fraction of constituents that attach to these particles. If, however, the removal of nutrients and dissolved constituents is the goal, the family of suitable BMPs is much smaller. The concentration of a constituent in the water column has an effect on the "efficiency" reported for the BMP. When high concentrations are present the BMP will typically show higher percentages of removal than when low inflow concentrations are encountered. For this reason, the reporting of effectiveness in terms of percent removed has to be questioned. This is evident when the water quality of the effluent is very good and the percent removal is low. This may be because the inflow concentration of the constituent of concern is also low.

Figure 7-4 compares the "efficiency of removal" in percent to the actual effluent concentrations for total phosphorous by a sand-peat filter as a function of influent concentration for one set of field tests. Tests for other constituents at this same site produce somewhat less definitive relationships, but a similar general trend was observed. Figure 7-4 is probably one of the more dramatic illustrations of the fact that the influent concentration affects the percent removal rate. It implies that a mathematical relationship can be developed for this site. It may even be possible to develop similar relationships for other BMPs and other sites, but that has yet to be demonstrated with sufficient variety of field data. Although a similar form for such an equation may possible, the regression coefficients are likely to differ for each constituent, each BMP type and, possibly, for each site. Nevertheless assuming such a relationship is possible, Figure 7-4 suggests a general form such as % Removed = $100*[1- (c/C_i)^k]$, in which c and k are regression constants and C_i is the influent concentration.

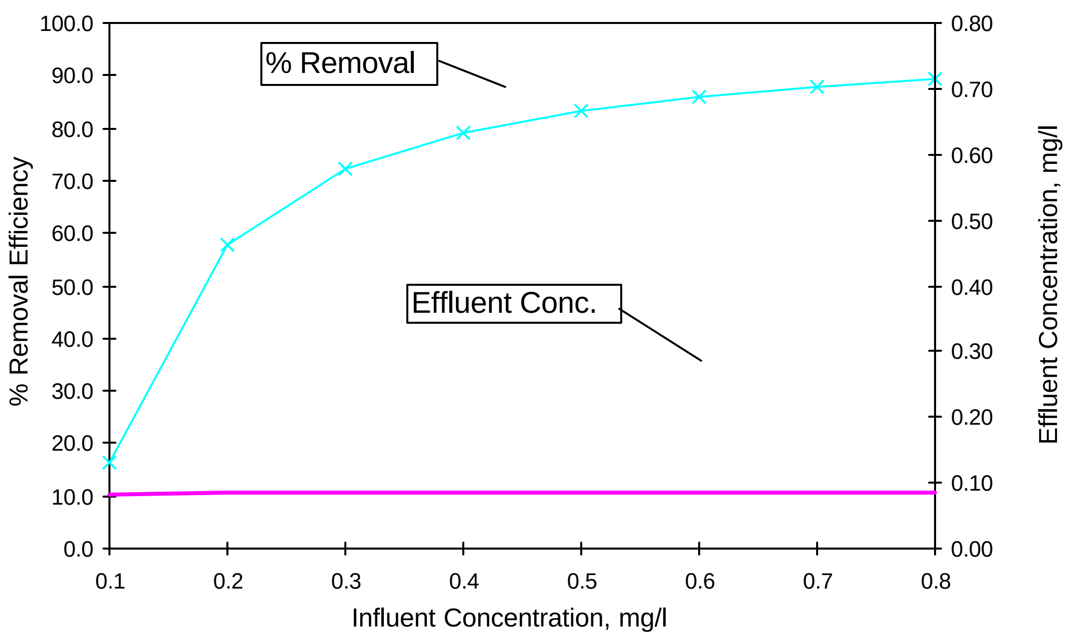

Figure 7-4. Total phosphorous "percent removal efficiency" and effluent concentrations for a peat-sand filter as a function of influent concentration. (Farnham and Noonan 1988).

Based on the preceding discussion, the definition of effectiveness should be based on more than “percent removal” of a constituent. It may be more appropriate to judge effectiveness against ranges of realistic effluent concentrations or some other parameter established by local watershed studies. It is not appropriate, however, to base this judgment on water quality standard developed for continuous dry weather flows, or on fixed percent removals of a constituent.

Often a community judges the “effectiveness” of a BMP by what other attributes it possesses, or what uses, other than stormwater management, it offers to the community. Thus, the incorporation of one or more other uses, namely multiple uses, such as active and passive recreation, enhancing or protecting wildlife habitat, flood control, and ground water recharge, into the BMPs design often is considered by the local residents as an “effective” facility. In contrast, a single-purpose, well functioning stormwater management facility sometimes is judged by its neighbors as a “nuisance.”

Operation and Maintenance

Operation and maintenance practices, or lack thereof, can significantly influence the actual effectiveness of structural BMPs. Most treatment controls do not require active operation of mechanical or chemical systems equipment, but all need adequate maintenance. Provision of such maintenance is assumed in the assessment discussions that follow. Also assumed in these discussions is that appropriate soil erosion controls are being vigorously practiced within the tributary catchment. If not, even the best designs can be rendered inoperative because of large sediment loads generated by uncontrolled construction sites.

On-Site or Regional Control

Another issue that needs to be considered is whether a BMP is used as an on-site or as a regional control. Very large numbers of on-site controls, sometimes exceeding several hundred or even several thousand, may be in place within any urban watershed. Reliably quantifying their cumulative hydrologic impacts on receiving waters becomes virtually impossible. Water quality, however, can be improved by both regional and on-site controls.

The degree of improvement for the cumulative effect in numerous on-site controls is, however, less predictable than with regional controls. This is because large numbers of on-site controls seriously complicate the quality assurance efforts during their design and construction. Large numbers of on-site controls are designed by a variety of individuals, which are then constructed by a variety of different contractors under varying degrees of quality control. Furthermore, very large numbers of BMPs will be maintained and operated in a variety of ways that are virtually impossible to anticipate or to effectively control.

Wiegand et al. (1989) estimated that regional controls are more cost effective because fewer controls are less expensive to build and to maintain than a large number of on-site controls. Regional controls can provide treatment for existing and new developments and can capture runoff from public streets, which is often missed by many of the on-site controls (Urbonas and Stahre 1993).

The major disadvantage of regional stormwater controls, such as detention basins, is that they require advanced watershed planning. Even when such a plan exists, the necessary up-front financing may be out of phase with the land development that is occurring in the watershed. Often the use of on-site controls is the only practical institutional, financial and political alternative.

Structural Best Management Practices: Performance

A number of the most commonly used structural BMPs are discussed next. Each is evaluated as to its effectiveness in addressing water quality, control of runoff volume and ability to moderate runoff rates in the receiving system. Also, when appropriate, some or all of the other points mentioned above are addressed.

Minimized Directly Connected Impervious Area

This practice has been around for a long time. However, up until recently it was recognized or defined as a stormwater management practice. In fact, it has been considered as inadequate and inappropriate for “good drainage” in urban areas. For certain types of urban land uses this practice can be a very effective stormwater BMP.

Unfortunately there are no data to show how much the implementation of minimized DCIA reduces surface runoff volumes, peaks and pollutant loads. The exact performance of this practice depends on which types of components show on Figure 7-2 are used at the site, the exact nature of the local geology, the type of soils and vegetative cover, and the nature of local climate. Under ideal conditions, surface stormwater runoff from low to medium density single family residential areas can be virtually eliminated for small rainstorms (i.e., storms with less than 13 to 25 mm (0.5 to 1.0 inch) of rainfall).

On the whole, this is a very effective stormwater BMP for low to medium density residential developments and for smaller commercial sites. Minimized DCIA is not a very effective BMP for high density residential developments and high density commercial zones, such as central business districts. This BMP demands that much of the land area of the development have a pervious surface, free of buildings and solid pavement. It may also not be appropriate for use when the general terrain grades are steeper that six percent. With highly erodeable soils, minimized DCIA may require even flatter terrain slopes.

This is one of the very few BMPs that, when used appropriately, can moderate the flow effects of urbanization in receiving waters, especially from the smaller storms. Also, for low to medium density developments, it can save on the cost of drainage systems and could be cost effective because the cost of storm drainage systems are reduced. In addition, with the use of stabilized shoulders, the surface area of pavement on public streets can be less than is used for a traditional street cross-section, thereby saving on initial construction and on its maintenance.

If misused, minimized DCIA can result in many problems to local residents that are often the result of poor drainage. Such problems include boggy mosquito breeding areas, poor snow removal and hazardous roadside ditches. On steeper slopes, erosion along some roadside and backyard swales has been observed. Also, property owners have been observed paving and filling poor draining, eroding or deep swales fronting their yards. Local policing and enforced preservation of the swales may be needed to prevent their loss through actions of local residents. Such enforcement is not a politically popular prospect for locally elected officials, especially if the citizens believe they are eliminating a problem on their front lawn.

This practice not be used for industrial and commercial sites that may be susceptible to spillage of soluble pollutants such as gasoline, oils, or solvents. The concern is prevention of soil and groundwater contamination.

Grass Swales

Removal rates exceeding 80% of TSS by grass swales are suggested by Whallen and Cullum (1988). Others suggest lower removal rates, on the order of 20 to 40% (UD&FCD 1992). The higher rates suggested by Whallen and Cullum may be possible when soils have very high infiltration rates and very slow flow velocities occur (i.e., less than 0.15 m/s). Grass swales appear to be best suited when terrain slopes are less than 3% to 4%, although some have suggested their use with terrain slopes as high as 6%. The limitations of site overlot grading during land development make the effective use of swales at higher slopes not practical. The use of swales is an integral part of the minimized DCIA practice.

The use of grass swales as stormwater collectors, instead of curb-and-gutter, slows the runoff process and can, under certain site conditions, also reduce the volume of runoff. Unless the swale is underlain by a clay layer, it is not recommended for use at industrial and commercial sites that may be susceptible to spillage of soluble pollutants such as gasoline, oils, and solvents for fear of soil and groundwater contamination.

Grass Buffer Strips

Grass buffer strips can remove larger particulates and promote local infiltration, provided the flow is kept very shallow and slow. Under ideal conditions, removals of 10 to 20% of suspended solids have been suggested (UD&FCD 1992). Buffer strips are an integral part of the minimized DCIA practice and are also an important part, of a number of practices that act in combination with each other. Thus the use of grass buffer strips is suggested whenever site conditions and land uses permit, upstream of swales, infiltration, percolation, wetlands, retention, and detention type of BMPs.

The use of grass buffer strips can slow surface runoff and, under certain site conditions, also reduce the volume of runoff, especially from small storms. Unless the grass buffer strip is underlain by a clay layer, it is recommended that it not be used at industrial and commercial sites that may be susceptible to spillage of soluble pollutants such as gasoline, oils, and solvents for fear of soil and groundwater contamination.

Porous Pavement

Field evidence indicates that properly designed modular pavement block porous pavement may be the only form of porous pavement that has a proven long-term successful performance record. This type of pavement has been in use since the mid-1970's with very few reported problems (Day et al. 1981, Smith 1984, and Pratt 1990). When porous pavement begins to clog, the simple removal and replacement of the soil or sand media in the pavement's openings can return it to full function.

On the other hand, Schueler et al. (1991) and others have reported that monolithic porous pavement surfaces tends to seal within one or two years after their installation. Once sealed, return the pavement to an acceptable working level is virtually impossible without total replacement of the pavement. Estimates of constituent removals for modular porous pavement range from 65 to 95%, depending on the constituent being monitored and the nature of local site and meteorological conditions.

The use of porous pavement can slow surface runoff and, under certain site conditions, reduce the volume of runoff, especially from the smaller storms. Unless porous pavement is underlain by an impermeable membrane and the stormwater is collected by an underdrain for surface discharge or post-treatment, the use of porous pavement not be considered for industrial and commercial sites that may be susceptible to spillage of soluble pollutants such as gasoline, oils, and solvents, for fear of soil and groundwater contamination.

Percolation Trenches

When properly operating, percolation trenches can remove up to 98% of the suspended solids in the stormwater and many of the constituents that are associated with these particulates. It has also been asserted that these facilities can also remove significant faction of nutrients, metals and other constituents from surface runoff. However, there is a concern that groundwater contamination may occur.

When operating, percolation trenches can reduce the volume of stormwater surface runoff. In fact, they can virtually eliminate direct surface runoff from small storms (i.e., less than 13 to 25 mm (0.5 to 1.0 inches) of precipitation).

Schueler et al. (1991) report that about 50% of percolation trenches constructed in the eastern U.S. have failed. He did not report on the nature and reason of these failures, although clogging within the trench and of its infiltrating surfaces were suspected. Two comprehensive field inspections, one in 1986 and the other in 1990, of percolation trenches were performed by the State of Maryland (Pensyl and Clement 1987, Lindsey et al.,1991). During the 1990 inspection of 88 percolation trenches, 51% showed signs of partial or major failure. Also reported was the fact that 31% of those failures occurred between 1986 and 1990. Although only 45% of installations reported a need for sediment removal maintenance, the inspectors reported a high incidence of sediment entering these trenches. Discussions with stormwater professionals working in the eastern U.S. indicates that the failure rate may actually be higher in 1996 than was originally reported by Schueler et al. (1991) and Lindsey et al. (1991).

It is possible to postulate from the inspectors' descriptions that clogging of percolation trench surfaces and groundwater mounding are the two most likely contributors to the reported failures. Groundwater mounding can develop under and around a percolation trench, actually surfacing within the trench (Stahre and Urbonas 1990, Colorado Storm Water Task Force 1990).

Clearly, the use of this practice should not be encouraged until sound engineering design guidance is adopted, possibly similar to the methodology suggested by Urbonas and Stahre (1993), including pre-filtration of stormwater before it enters a trench and the use of a comprehensive groundwater hydrologic investigation during design. Furthermore, percolation trenches should not be used at industrial and commercial sites that may be susceptible to spillage of soluble pollutants such as gasoline, oils, and solvents for fear of soil and groundwater contamination.

Infiltration Basins

Properly operating infiltration basins can remove anywhere from zero to as high as 70 to 98% of the pollutants found in stormwater, depending on the constituent and site conditions. Also, when operating, infiltration basins can reduce the volume of stormwater runoff and virtually eliminate direct surface runoff for small storms (i.e., less than 0.25 to 0.5 inches of precipitation).

Two comprehensive field inspections, one in 1986 and the other in 1990, of infiltration basins were performed by the State of Maryland (Pensyl and Clement 1987, Lindsey et al. 1991). During the 1990 inspection, 73% of the 48 installations inspected were judged as "failed." The inspectors reported that only 41% of the inspected infiltration basins needed sediment removal maintenance. From the inspectors' descriptions, groundwater mounding appears to have contributed to some of the reported failures. Their rate of failure implies a lack of sound engineering in their design and/or construction. Lack of maintenance may have contributed to some of the reported failures, but the findings by Lindsey et al (1991) suggest that other factors were at work in many of the reported failures.

This practice should not be encouraged until sound engineering design guidance is adopted, possibly similar to the methodology suggested by Urbonas and Stahre (1993). When operating properly, infiltration basins can reduce the volume of stormwater surface runoff. In fact, they can virtually eliminate direct surface runoff from small storms (i.e., less than 13 to 25 mm (0.5 to 1.0 inches) of precipitation).

Infiltration basins not be used for industrial and commercial sites that may be susceptible to spillage of soluble pollutants such as gasoline, oils, and solvents for fear of soil and groundwater contamination.

Media Filter Basins and Filter Inlets

Filters can be very effective BMPs where land area is at a premium, but they need regular maintenance. When they are undersized or are left unmaintained, media filters accumulate a layer of fine sediment on their surface and seal. Once clogged, a media filter drains at very slow rate and stormwater runoff either ponds upstream of the filter or bypass it (Urbonas et al. 1996b). Either condition is unacceptable. In the first case the ponding water may be a nuisance or create dangerous situations. In the latter, only a fraction of the stormwater that arrives at the filter actually receives the treatment efficiencies typically reported for sand filters.

To compensate for this potential problem, oversizing the filters or providing stormwater capture detention volume upstream that is sized in balance with the filter's clogged flow-through rate is necessary. Both approaches, that is, oversizing and upstream detention, might be used. Oversizing the filter can also reduce the necessary frequency of maintenance. Providing an extended detention basin for pretreatment is suggested by Urbonas and Ruzzo (1986) and Chang et al. (1990). Field experience with designs that have a full presettlement detention basin appear to have much longer life before the filter surface requires cleaning and/or the media needs replacement.

Tests using media other than sand, such as peat, peat-sand mix, compost-sand mix show them to clog faster than sand filters (Galli 1990, Stewart 1989). This means their longevity at acceptable hydraulic flow through rates may be very poor and they may be even less attractive and functional than filters using sand as the media for filtration.

When a media filter is located within an underground vault, such as a water quality inlet, it is out-of-sight-and-out-of-mind and is likely to not receive the needed maintenance attention of a visible surface facility. Regular inspection programs are a must if media filters are used in order to assure their continued proper operation.

A media filter basin or inlet, without an upstream detention basin, has no effect on stormwater runoff flow rates. As a result, these facilities have no potential for attenuating increases of runoff rates from urban areas.

Sand filter inlets suggested by Shaver and Baldwin (1991), while effective, are expensive to construct. Above ground filter basins are also significantly more expensive to build than detention basins. It has been argued that media filters are most likely to be used where land costs are very high. However, comparisons of filters, designed with clogging and minimal maintenance in mind, to detention basins and retention ponds revealed that the filters require similar land areas to construct as do detention basins. If this is the case, as recent findings have suggested (Urbonas et al. 1996 b), the cost of functional media filters may actually be more than detention basins. Also, based on the analysis of various unit operations and filter clogging processes measured under laboratory and field conditions, Urbonas (1997) suggested an engineering design and analysis procedure for stormwater runoff sand filters. This procedure provides for design and water quality performance by accounting for runoff probabilities, suspended sediment loads in stormwater, volumes processed by the filter and volumes bypassing it and the maintenance (i.e., cleaning) for the filter media.

Water Quality Inlets

Episodic evidence reported by a number of observers over a number of years and more recently confirmed by Schueler et al. (1991) through field tests, indicates poor performance by water quality inlets (i.e., sand and oil and grease traps). These devices, depending on their complexity, can be very expensive to construct and to maintain and appear to offer very little water quality enhancement in return. Also, these devices provide no peak flow or volume control capability. Additional, research and development efforts are likely to occur in this area.

Swirl-Type Concentrators

Swirl concentrators are designed to process stormwater up to a stated design flow rate and to by-pass flows that exceed this rate. When they work properly, swirl concentrators can remove the heavier sediment particles and many of the floatables found in stormwater. They have not been shown to be effective in the removal of neutrally buoyant solids such as plastic bags, oils, greases or very small or light suspended particles. Also, they have been known to perform below expectations for larger and smaller flow rates than the specific design rate.

New commercial devices such as StormCeptor™ are currently being field tested and objective results on their performance should begin to show up in literature within the next two years. These devices can be expensive to construct and to maintain. Swirl concentrators provide no peak flow or volume control capability unless they have a detention basin upstream of them to equalize flows.

Extended Detention Basins

The performance of a relatively large number of extended detention basins have been documented by field and laboratory tests. For example, removal rates for TSS range from 10 to 90%, depending on the constituent being sampled, the geometry of the installation, and the local climate. For properly sized and designed extended detention basins, removal rates for TSS, lead and other undissolved constituents are only somewhat less than observed for retention ponds and wetlands. Although sedimentation is the main treatment process in these basins, other associated processes are known, or are suspected, to be at work. These include flocculation, agglomeration, ion exchange, adsorption, physical resuspension of particulates, and solution.

According to Grizzard et al. (1986), to serve as a water quality enhancing BMP, a detention basin needs to hold stormwater runoff for much longer periods of time than a detention basin that is used for the purpose of controlling peak runoff rates. Thus the term extended detention basin has been coined. For the smaller storms, namely the storms that produce somewhere between the mean and the 90th percentile surface runoff volumes, the minimum emptying time of the captured volume needs to be between 24 to 48 hours (Grizzard et al. 1986, Urbonas et al. 1990, Urbonas and Stahre 1993). To be most effective for water quality enhancement and to mitigate some of the effects of increased surface runoff from an urbanizing area, the longer of the suggested drain times needs to be used with the larger design storm (i.e., probably exceeding 13 to 20 mm [0.5 to 0.75 inches] of precipitation) and the shorter drain times with the smaller events (i.e., probably less than 13 mm [0.5 inches] of precipitation).

Extended detention basins can be designed to control the flow rates from a wide range of small to large storm runoff events. However, the most difficult storm events to control are the small ones from small tributary areas. The outlet needed to throttle flows down to very low levels needs to have very small openings, which are susceptible to clogging. Control of the larger events is accomplished by the detention volumes that surcharge the water quality extended detention volume. Also, an extended detention basin does not reduce the volume of the runoff that enters it.

Retention Ponds

Hartigan (1989) stated that retention ponds can remove 40%-60% of phosphorus and 30%-40% of total nitrogen. Other studies show lesser annual removal rates. Studies in Washington, DC area by Schueler and Galli (1992), indicate that the permanent pools characteristic of retention ponds can act as heat sinks resulting in warm water releases and, therefore, retention ponds may not be appropriate for use if they discharge to streams that support trout. Often a retention pond is sized to remove nutrients and dissolved constituents, while any pool that may be associated with an extended detention basin is much smaller and is provided for aesthetics, namely, to cover the solids settling areas with water.

The major features of a state-of-the-art design of a retention pond includes a permanent pool and an emergent wetland vegetation bench called the littoral zone. The pond provides a volume of water where the solids can settle out during the storm event (i.e., active sedimentation period) and during the periods between storms (i.e., quiescent sedimentation period). Sedimentation can also remove that fraction of nutrients and soluble pollutants that adhere to sediment particles. The littoral zone provides aquatic habitat, enhances the removal of dissolved constituents through biochemical processes and helps to minimize the formation of algae mats. Sometimes the pond has surcharge detention storage volume above it that can be used for flood control and to enhance sedimentation during storm runoff periods.

Retention ponds, on the average, can do a noticeably better job at the removal of nutrients than extended detention basins. However, the reported variability in performance ranges for retention ponds indicate that much remains to be learned about their performance. This knowledge will be needed to develop a reliable design guidance for nutrient removals. Nevertheless, the use of retention ponds appears to be more effective than extended detention basins, filters, swirl concentrators, swales, buffer strips, and other BMPs. A possible exception is constructed wetlands when nutrient loading is of concern, namely for urban watersheds that are tributary to reservoirs and lakes and to tidal embayments and estuaries.

For retention ponds to be effective in the removal of nutrients, the permanent pool has to have two to seven times more volume than an extended detention basin (Hartigan 1989), depending on local meteorology and site conditions. As a result, more land area is needed than is required for a detention basin and costs can be 50% to 150% higher than for an extended detention. This increase may not be as significant if the pond has surcharge storage for drainage or flood control peak-shaving.

Retention ponds can be more aesthetic than extended detention basins because sediment and debris accumulate within the permanent pool and are out-of-sight. Large retention basins are sometimes used as property value amenities, sometimes permitting surcharge in the "lake front" property cost. However, if the tributary area does not have sufficient runoff during the year, detention ponds can dry out or become unsightly "bogs" and become a nuisance to the adjacent property owners.

Thus, some of the issues to consider when choosing a retention pond are:

1. Can the tributary catchment sustain a sufficient base flow to maintain a permanent pool?

2. Are the receiving waters immediately downstream particularly sensitive to increased effluent water temperatures that can result from sun's warming of the pond?

3. Do existing wetlands at the site restrict the design of the permanent pool of the pond?

4. Are water rights available for the evapotranspiration losses in states with a prior appropriation water rights laws?

Retention ponds can be designed to control the flow rates from a wide range of small to large storm runoff events. As with extended detention basins, the most difficult storm runoff events to control are the small ones, especially the ones from small tributary catchments. The outlet needed to throttle flows down to very low levels needs to have very small openings, which are susceptible to clogging. Control of the larger events is accomplished by the detention volumes that surcharge above the permanent pool. However, a retention pond does not appreciably reduce the volume of the runoff that enters it.

Wetlands

Properly designed and operated wetlands, on the average, can remove significant percentages of total phosphorous, nitrogen, TSS and other constituents from urban stormwater runoff (Strecker et al. 1990). However, when compared statistically to other BMPs, wetlands appear to remove most of the constituents found in stormwater to about the same percentages that one can expect from extended detention basins and retention ponds. The claim that wetland basins are more effective in the removal of nutrients from stormwater is probably true for some installations, while other installations appear to be less effective.

The ranges in the performance data reported for wetland basins tell us that much has to be learned about how wetlands function and what constitutes a reliable design, especially for nutrient removals. Well controlled field investigations are needed to identify which field conditions and design parameters produce consistently good pollutant removals.

For example, Walesh (1986) describes the planning and design of a restored wetland in series with a sedimentation pond intended to substantially reduce the transport of suspeded solids and phosphorous into an urban lake. Oberts et al. (1989) presents the results of a 29 month monitoring study of the system during which 19 rainfall and four snowmelt events were monitored. Total phosphorous removals were at or above 50% for rainfall events. The sedimentation pond-wetland system removed 90% the total suspended solids for all monitored rainfall and snowmelt events. The successful performance of the system, which, incidentally, exceeded the performance of four other similar systems in the area, was attributed to several factors. For example, pre-settling of stormwater runoff in the sedimentation pond prior to discharge into the restored wetland is important. The volume of the permanent storage pool should be at least 2.5 times the runoff volume generated from the mean summer storm. The area of the permanent pool in the sedimentation basin should be about two percent of the impervious area of the watershed and the pool should have the maximum depth of over four feet.

There are little data in literature on the performance of wetland channels. As a result, current estimates of their effectiveness are speculation and educated guesses. Extrapolations from limited data (Urbonas et al. 1993) suggest that properly sized and designed wetland channels compare well with the performance of wetland basins for nutrient removal during small storm runoff events and during dry weather flow periods.

Another claim found in the literature is that the removal of nutrients by wetlands requires regular harvesting of wetland basins. This claim, however, does not appear to be well substantiated by field data. In fact, the limited information that is available shows regular harvesting to be of questionable value in increasing nutrient removal rates. Mechanisms in addition to plant uptake appear to be responsible for nutrient uptake in nutrient removals by wetlands.

The actual mechanisms for the removal of phosphorous and of nitrogen by wetlands are probably different. Phosphorous removals are most likely associated with the removal of solids, including ionic adhesion to solids and uptake of the dissolved fractions by algae (i.e., eutrophication). When algae die, they are deposited on the bottom “muck” or benthos, taking along some of the phosphorus with them. However, these benthal deposits can release phosphorous under reducing conditions. Much of the phosphorous in the benthos, however, becomes permanently trapped and unavailable for release to the water column. Thus, the removal of the accumulated benthos (i.e., mucking out) has to take place occasionally to keep wetland basins and wetland channels operating satisfactorily.

Although the removal of nitrogen is, in part, the byproduct of algae and other plant uptake, nitrites and nitrates appear to be too mobile for effective removal rates by this process alone. Aerobic and anaerobic denitrification appears to also take place within wetlands. This process takes place in wetlands used for the polishing of wastewater treatment plant effluent, mostly in the root zones and on the biological film that is found on all wetland plants and their roots. Much of the current wetland treatment technology was developed for the treatment of wastewater (Nichols 1983, Kedlec and Hammer 1980) and has not had the benefit of the development for use under the vastly different conditions that occur during wet weather conditions. However, even for the uniform flow and loading conditions of a wastewater treatment plant, wetlands have a limit in how much nutrient loading they can accumulate before degradation in performance is experienced (Watson, et al. 1989). Much has yet to be learned about the actual bio-chemical processes at work in wetlands, especially for the treatment of stormwater, before it is possible to design them with confidence for stormwater treatment.

A wetland basin can be designed to control the flow rates from a substantial portion of small storm runoff events and to also control the flow rates from most large storm runoff events. The approach is to design them for the flow control function like one would design a retention pond.

Wetland channels can help control the flow rates of the smaller runoff events, however to a lesser degree than a wetland basin, an extended detention basin or a retention pond. Wetland technology is emerging as a viable tool for stormwater management but suffers from lack of prolonged field studies. Such studies are needed to answer questions such as how different wetland design configurations respond to stormwater loadings over an extended number of years when operating in the wide variety of climates, geologic settings and meteorological conditions found in the U.S.

Summary on Best Management Practice Effectiveness

Non-Structural Best Management Practices

A quantified assessment of how much effect non-structural BMPs have on the receiving water quality or the enhancement of its aquatic life has yet to be made. So far many surrogate measures have been used in an attempt to quantify their effectiveness. For example, the measure of gallons of oil recycled has been used to demonstrate how “effective” this non-structural BMP is, but this does not in any way quantify the number of gallons of oil this program eliminates from being transported to the receiving waters by the stormwater system. In other words, a surrogate measure may or may not have any relationship to the BMP’s effectiveness in reducing any specific pollutant from reaching the receiving waters or determining the impact on the receiving system.

Most of the suggested practices are supported by good intentions. For the most part they are a collection of common sense practices and measures. This leads to the belief that non-structural BMPs should provide a positive benefit when implemented and used, but data are needed to quantify the costs and benefits. If nothing else, non-structural BMPs should result in a cleaner looking urban landscape.

Structural Best Management Practices

The Definition of Effectiveness

Much more field performance data are available for structural than for non-structural BMPs. Table 7-2 summarizes the removal "efficiencies" of several structural BMPs most frequently used in the U.S. The table includes the information found through extensive literature reviews conducted for this report and by a Colorado task force (Colorado Storm Water Task Force 1990) and the Denver, Co area Urban Drainage and Flood Control District (UD&FCD 1992). What is of note are the wide ranges in the reported percent removals. Despite that, when properly designed for local soil, groundwater, climate and site geology, all BMPs will remove pollutants from stormwater to some degree. What is in question is how much at any given site and for how long will the BMP continue to function at those performance levels.

Table 7-2. BMP pollutant removal ranges in percent. (Bell et al. 1996, Colorado Storm Water Task Force, 1990, Harper & Herr 1992, Lakatos & McNemer 1987, Schueler 1987, Southwest 1995, Strecker et al. 1990, UD&FCD 1992, USGS 1986, US EPA 1983, Veenhuis et al. 1989, Whipple & Hunter 1981).

Type of Practice	TSS	Total P	Total N	Zinc	Lead	BOD	Bacteria
Porous Pavement	80-95	65	75-85	98	80	80	n/a
Grass Buffer Strip	10-20	0-10	0-10	0-10	n/a	n/a	n/a
Grass Lined Swale	20-40	0-15	0-15	0-20	n/a	n/a	n/a
Infiltration Basin	0-98	0-75	0-70	0-99	0-99	0-90	75-98
Percolation Trench	98	65-75	60-70	95-98	n/a	90	98
Retention Pond	91	0-79	0-80	0-71	9-95	0-69	n/a
Extended Detention	50-70	10-20	10-20	30-60	75-90	n/a	50-90
Wetland Basin	40-94	(-4)-90	21	(-29)-82	27-94	18	n/a
Sand Filters (fraction flowing through filter)	14-96	5-92	(-129)-84	10-98	60-80	60-80	n/a

Note: The above-reported removal rates represent a variety of site conditions and influent-effluent concentration ranges. Use of the averages of these rates for any of the reported constituents as design objectives for expected BMP performance or for its permit effluent conditions is not appropriate. Influent concentrations, local climate, geology, meteorology and site-specific design details and storm event-specific runoff conditions affect the performance of all BMPs.

The current definition of "effectiveness" in terms of percent removal is flawed, whether it is defined as the reduction in concentration or as the load of a constituent removed from stormwater runoff. A better measure needs to be developed to define how well a specific structural BMP is performing. This point was illustrated earlier by the example for the removal of phosphorous by a sand-peat filter. That example showed that the "percent removal" increased with the concentration of phosphorous in the influent while the concentrations in the effluent remained constant. As a result, "worst" performance was attributed to the storm runoff that had the cleanest water entering the filter.

Ironically, one can argue that a performance standard based on percent removals would be met most frequently when the watershed was kept in the most unclean condition, while the watershed with the best use of source controls would produce the worst performance record for the filter. This, despite the fact the filter's effluent was identical for both.

The nature of a redefined performance measure has yet to be determined. Such a standard will most likely be tailored for each structural BMP. It will have to address more than one question since the purpose for the selection and use of each BMP will vary with the local goals and objectives. As an example, is the BMP needed primarily to remove floating trash and sediment or is the removal of phosphorous or nitrogen the main goal, or is it the mitigation of increased runoff rates or volumes the main reason for the selection of the BMP? These and other, yet to be identified questions and issues will need to be addressed when developing a new "effectiveness" matrix for each BMP and its design.

Research and Design Technology Development Needs

While much is known about the performance of some of the discussed BMPs, such as retention ponds and extended detention basins, much more must be learned. For some BMPs, insight into their pollutant removal mechanism and characteristics is just beginning. For some areas of the U.S. there may even be sufficient information to relate BMP performance to a set of design parameters such as the size and imperviousness of the tributary watershed. This does not deny the fact that all BMPs can still benefit from well conceived and well controlled prolonged field studies.

An approach towards a systematic approach for performing field evaluations of BMPs was suggested by Urbonas (1995). Although there appears to be a significant number of BMP tests in the U.S. and other countries, what is lacking is a consistent scientific approach and the reporting of key design and tributary watershed parameters for the BMPs being tested. As a result of the data acquisition approach suggested by Urbonas, the American Society of Civil Engineers and the USEPA in 1996 entered into a cooperative agreement to define the data and information needs for such studies, to develop a data base software package for field investigators to use, to find and extract existing data on BMP performance, and to complete an initial evaluation of such data by the end of 1999.

To have significance, and to identify issues that arise over the near term, field investigations of BMPs probably need at least five years of data gathering, otherwise important performance information is likely to be missed. For some BMPs, performance is affected by maintenance and/or operations. For others, the maintenance needs will not become apparent for several years and prolonged testing is the only way to answer the question of how their performance will vary over time. Yet for other BMPs, performance may change over time. Such information will be needed to decide if and when such BMPs will need to be replaced or rehabilitated. Only when such information and much field performance data are available, are fully analyzed, and reliable relationships between performance and design parameters are quantified, will practitioners be in a position to design BMPs with performance expectations in mind. At this point there are too many unanswered questions on how to design BMPs for a stated performance level, whatever it may yet turn out to be. Among the questions that need to be answered are what kind of operations and maintenance are needed to provide the desired level of performance, what are the life cycle costs, and will they provide the desired results in the receiving waters for which they were selected or minimize the impacts of urbanization on those receiving waters?

Design Robustness

Robustness of BMP design technology is a factor that integrates what is known today about design. Robustness needs to be recognized when judging various BMPs for use. High robustness of design technology implies that, when all of the design parameters are correctly defined and quantified, the design has a high probability of performing as intended. In other words, the design technology is well established and has undergone the test of time. Low robustness implies that there are many uncertainties in how the design will perform over time. All facilities are assumed to be properly operated and maintained when judging design robustness.

Table 7-3 is an edited version of the collective opinion of many senior professional engineers involved in the development of the 1998 WEF & ASCE manual of practice for the selection and design of stormwater quality controls. The differences between this table and Table 5.6 of the MOP are based on further evaluation of the issues considered during the assessments at the time the MOP was being prepared. The weakest design link actually governs the overall design robustness of each BMP.

Runoff Impacts Mitigation

The emerging theme in the environmental community is the need for stormwater surface runoff flow control in urban and urbanizing areas. This concept has a long history of study and discussion in stormwater engineering literature. Changes in surface runoff hydrology with urbanization have been discussed by the engineering community now for over 20 years (McCuen 1974, Hardt and Burges 1976, Urbonas 1979, Glidden 1981, Urbonas 1983, Walesh 1989). The challenge until now has been to control the peak runoff rates for drainage and flood control purposes. This focus led to the control of peaks from larger storms such as the 5-, 10- or/and the 100-year flow rates. Use of on-site and regional detention became popular in some areas of the U.S.

Table 7-3. An assessment of design robustness technology for BMPs[1].

BMP Type	Hydraulic Design	Removal of Constituents in Stormwater		Overall Design Robustness
		TSS/Solids	Dissolved	
Swale	High	Low-Moderate	None-Low	Low
Buffer (filter) strip (2)	Low-Moderate	Low-Moderate	None-Low	Low
Infiltration basin (2)	Low-High	High	Moderate-High	Low-Moderate
Percolation trench	Low-Moderate	High	Moderate-High	Low-Moderate
Extended detention (dry)	High	Moderate-High	None-Low	Moderate-High
Retention pond (wet)	High	High	Low-Moderate	Moderate-High
Wetland	Moderate-High	Moderate-High	Low-Moderate	Moderate
Media filter	Low-Moderate	Moderate-High	None-Low	Low-Moderate
Oil separator	Low-Moderate	Low	None-Low	Low
Catch basin inserts	Uncertain	n/a	n/a	n/a
Monolithic porous pavement (2)	Low-Moderate	Moderate-High	Low-High (3)	Low
Modular porous pavement (2)	Moderate-High	Moderate-High	Low-High (3)	Low-Moderate

Notes:
1) Weakest design aspect, hydraulic or constituent removal, governs overall design robustness.
2) Robustness is site-specific and very much maintenance dependent.
3) Low-to-moderate whenever designed with an underdrain and not intended for infiltration.
4) Moderate-to-high when site conditions permit infiltration.

and Canada. In the early 1970s the State of Maryland was the first to require the control of the two-year peak flow rate for the stated purpose of controlling stream widening and erosion that were observed to take place after urbanization. However, Maryland acknowledges that the success of these requirements was well below expectations.

What is clear is that scientifically untested policies have little chance of success, despite their good intentions. They can lead to waste of resources and provide little or no environmental benefit, especially when applied through regulatory mandates. A better approach would be to develop long term field test beds before nationwide requirements or guidance on runoff flow controls are promulgated. Too much variety in community needs, ecological integrity protection, fiscal resources, physical settings of the receiving waters, climates, and geology exist throughout the U.S. to suggest a generic methodology. These type of decisions best rest at the specific watershed level and the state in which it is located.

The current demand by some for runoff flow controls has to be approached very carefully, lest resource (primarily in the form of land area and urban sprawl) consumption occurs without the commensurate environmental return. It is also possible to set up policies that physically cannot be met, such as “no increase in surface runoff volume.” Although some sites, under certain rainfall regimes, may be able to meet this standard after urbanization, this is probably not a realistic expectation at all sites, at all times.

Some of the BMPs discussed here can provide peak runoff rate mitigation. Others can provide mitigation of surface runoff peak rates and of runoff volume increases. None can totally eliminate the effects of urbanization. The most promising candidates for mitigating peak flow rates are the ones that capture runoff volume and release it over an extended period of time. These include retention ponds with extended detention surcharge volume over their permanent pool, extended detention basins, wetland basins and any other BMP that captures and slowly releases surface runoff.

Runoff volume reduction is much more difficult to achieve. Some of the BMPs discussed here can do so whenever site conditions permit. Trying to use such BMPs for volume reduction proposed under unfavorable site conditions is not only unwise, it is a gross denial of reality and physical limitations of the practices and the site conditions. For instance, these practices have only a limited potential for volume reduction when the development site is very steep, or has very tight or highly erosive soils, or is located in a region that cannot support a healthy and robust vegetative ground cover. Nevertheless, each of the BMPs is rated in the next section for their potential ability to reduce surface runoff flow rates and volumes.

Summary of the Usability of the Evaluated BMPs

Table 7-4 was designed to consolidate the foregoing discussion. It contains ranking scores from 1 through 5, with 5 being the score for the highest positive aspect and (-5) indicating the highest negative aspect of each BMP. As an example, potential for failure is considered to be a negative aspect, while the potential for mitigating the increases in surface runoff volume is considered a positive aspect. The rankings are based not only on what is reported in the literature, but also are based on experience in stormwater management. Clearly, the scores are somewhat subjective and further discussion and study are needed.

At any rate, the composite average rating scores reveal a ranking that integrates all of the aspects discussed and considered so far. Note the groupings of the BMPs. All ratings were ranked from one through 16 and then were segregated into five groups,

Table 7-4. Summary assessment of structural BMP effectiveness potential.

Structural BMP Type							Applicability for Given Land Use			Design Technology Robustness						
	Water Quality Improvement	Flow Rate Control	Runoff Volume Reduction	O & M Needs (1)	Sensitivity To Site Conditions	Failure Potential	Low to Medium Residential	High Density Residential Medium Density Comm'l	High Density Commercial Industrial	Hydrologic and Hydraulic	Water Quality	Potential for Thermal Increases	Potential for Groundwater Contamination	Average of All Ratings	Rank Order of Rating Averages	Groupings by Rankings
Minimized DCIA (2)	4	5	5	-3	-4	-2	5	3	1	4	4	-1	-3	1.09	**1**	***1***
Extended Detention Basin	4	5	1	-2	-2	-2	4	4	3	4	4	-3	-2	0.97	**2**	***1***
Retention Pond (3)	5	5	1	-2	-3	-1	4	4	3	4	4	-4	-2	0.97	**3**	***1***
Wetland Basin (3)	5	5	2	-3	-4	-1	4	4	2	4	3	-3	-2	0.85	**4**	***1***
Porous Pavement: Modular w/ Underdrain	3	5	1	-4	-2	-2	1	5	5	4	3	-2	-2	0.70	**5**	***2***
Infiltration Basin (2)	4	5	5	-4	-5	-4	5	5	2	3	4	-1	-4	0.64	**6**	***2***
Wetland Channel (3)	3	3	2	-3	-3	-1	4	4	2	4	2	-2	-2	0.58	**7**	***2***
Porous Pavement: Modular w/ Infiltration (2)	4	5	4	-4	-5	-4	4	5	5	4	4	-2	-4	0.61	**8**	***3***
Media Filter	4	1	0	-5	-1	-3	1	3	5	3	4	-2	-1	0.27	**9**	***3***
Percolation Trench (2)	4	4	4	-5	-5	-5	2	3	4	3	4	-1	-5	0.09	**10**	***4***
Grass Swale (2)	2	3	1	-3	-3	-2	5	3	1	3	1	-2	-2	0.09	**11**	***4***
Grass Buffer Strip (Grass Filter Strip) (3)	2	2	2	-3	-3	-2	5	3	1	2	1	-1	-2	0.09	**12**	***4***
Swirl-type Concentrator	3	1	0	-5	-1	-2	1	2	4	3	2	-2	-1	0.03	**13**	***4***
Dry Well (2)	4	4	4	-5	-4	-5	2	3	4	2	2	-1	-5	-0.09	**14**	***5***
Porous Pavement: Monolithic (2)	4	3	4	-5	-4	-5	3	3	3	2	3	-3	-4	-0.18	**15**	***5***
Water Quality Inlet	1	0	0	-5	-1	-3	1	2	3	3	1	-1	-1	-0.36	**16**	***5***

(1) Routine or rehabilitative maintenance, or both. **(2)** When site conditions permit. **(3)** When local climate site conditions permit

four with positive average ratings and one with negative ratings. The BMPs with the best average ratings were put into Group 1 and those with the lowest ratings into Group 5. These five groupings are as follows:

Group 1:	Minimized Directly Connected Impervious Area Extended Detention Basin Retention Pond Wetland Basin
Group 2:	Modular Porous Pavement With an Underdrain Infiltration Basin Wetland Channels
Group 3:	Modular Porous Pavement With Infiltration Media Filter
Group 4:	Percolation Trench Grass Swale Grass Buffer (Filter) Strip Swirl Concentrator
Group 5:	Dry Well Monolithic Porous Pavement Water Quality Inlets

Stormwater Systems of the Future

Stormwater management in urban centers of the U.S. is in the process of metamorphosis. The shift is away from rapid disposal of surface runoff. Instead governing bodies are looking at urban stormwater runoff impacts on the receiving waters and how to minimize these impacts to a “maximum extent practicable.” Urbanization affects the environment, including the nature and quality of the receiving waters. This inescapable fact is driven by population growth. Although some believe that such impacts can be eliminated, the laws of conservation of space, matter and energy consign challenge such beliefs. Therefore, society has to find ways to make wise and cost effective choices to minimize the impact of population growth and its resultant urbanization on the receiving waters. Too ambitious a program can have profound economic impacts on the public and can become economically and politically self defeating. At the same time, doing nothing can have a profound detrimental effect on the receiving waters that also translates to harsh economic impacts on the local public as well.

As much as some may wish it was not so, barring major natural disasters continued urban growth has to be assumed as a given. How stormwater runoff from this growth is managed will define how urban centers will evolve in the next century. The challenge is to find systems and their components that both serve the environment and the needs of the urban communities to the maximum practicable level desired by the U.S. Congress, the individual states and the local municipal populations. Doing this requires learning how to moderate impacts of urbanization on each receiving system as it relates to the local geography, geology and climate, realizing that all impacts cannot be eliminated. At the same time, the systems should not have draconian impacts on urbanization, a natural effect of population growth. With these thoughts as background, the following ideas are offered as possible stormwater management systems of the future.

Use of Combined Wastewater and Storm Sewer Systems

Some have suggested the return to the use of combined wastewater and stormwater systems, that is CSS. The suggestions range from complete coverage of all new urban areas by such systems to the limiting of their use to only high density commercial and industrial areas. Most of these suggestions include detention elements to modulate flow rates into such systems and to limit the size of the conveyance sewers and treatment works. Such systems would result in the first flush of larger storms and all runoff from smaller storms being captured and treated through publicly owned wastewater treatment plants before release to the receiving systems. Much of the stormwater entering headwater streams would be diverted to such systems, thus reducing the impacts of increased stormwater runoff into these streams.

On the other hand, these systems would have occasional combined sewer overflows. In the process of diverting stormwater runoff from the headwater streams, other hydrologic changes will likely occur, such as groundwater depletion and reduced base flows in perennial streams. The biggest drawback to these systems is the cost of their construction, operation, and maintenance. Much bigger sewers would be needed to transport stormwater to a treatment plant, even with detention, than are needed to deliver stormwater to the nearest receiving waterway. The treatment plant also needs much greater capacity to handle the 10 to 30 percent of the days during any given year when wet weather flows actually occur. Combined systems need a much higher level of maintenance than separate sewer and storm sewer systems. Also, these systems will require an increased use of non renewable resources (i.e., electric power, petroleum based fuels and chemicals) to treat stormwater. Whether these added costs are justified will depend on site specific conditions such as the receiving waters and the impacts on them that are being mitigated, the community's size and economic strength.

With the foregoing in mind one scenario for a stormwater system of the future would consist of a hybrid system, one that serves part of the urban area with a combined wastewater and separate stormwater system and the remaining part with a separate stormwater system. More specifically it would consist of the following:

1. The use of good housekeeping, and non-structural BMPs, is well established and practiced, with especially strong emphasis on control of illegal and illicit discharges of contaminants and the control of erosion during construction.

2. Major facility needs of the stormwater management system would be based on a watershed, or sub-watershed level master planning process. The community would be involved in the process.

3. The process would account for future growth, drainage system and other infrastructure needs of the community and integrate all of these with community needs such as open space, recreation, jobs, and transportation. Impacts, growth trends, costs, maintenance needs, benefits and other issues and needs would be identified and, when possible, quantified.

4. Use of the minimized DCIA elements wherever practicable and possible in residential areas and commercial parts of the community and in areas such as parks, golf courses, playgrounds, playing fields, churches, and recreation centers.

5. An extensive use of surface infiltration and flow retardance elements such as grass buffers, swales, porous pavement, and infiltration basins when site geology and site conditions permit.

6. Extensive use of on site or regional extended detention basins, retention ponds and/or wetland basins for all urbanizing areas, whether connected or not, to the CSS.

7. Sized to capture a water quality volume to also help mitigate increases in surface runoff from small events.

8. When the drainage system and public safety requires, provide for a surcharge flood control detention above the water quality capture volume.

9. All high density commercial areas, gasoline stations, other commercial areas subject to surface contamination by chemicals or high concentrations of nutrients, and industrial areas subject to chemical surface contamination be connected to a combined sewer system.

10. All connections to the CSS would be made through water quality capture volume basins.

11. All releases from the water quality capture basins connected to the CSS would be controlled by an intelligent real-time flow management system designed to meet the conveyance and the treatment plant system's capacities.

Use of Separate Stormwater Systems

Use of a hybrid combined wastewater and stormwater system may not be the best or practical option for the majority of communities in U.S. As discussed earlier, these systems are likely to be more expensive, in terms of life cycle costs, to build and operate than two separate systems, one for wastewater and the other for stormwater.

When a hybrid combined system is not a cost effective or practical solution, what is left is a separate stormwater management system that uses various management and land use development practices to control stormwater runoff quality and quantity as close to the source as practicable. The goal of an ideal separate stormwater management system of the future would be to select stormwater management components that best mitigate the impacts of urbanization on the receiving waters for the community in a most practical and cost effective manner. Similar to the hybrid combined system, a separate stormwater system of the future would capture the first flush of larger storms and all runoff volume from smaller storms. The captured volume would receive passive treatment by the BMP before stormwater is released to the receiving systems within or downstream of the community. Such a system could significantly reduce the impacts of increased stormwater runoff and its contaminants on these receiving waters.

With the foregoing, a possible scenario for a stormwater system of the future is as follows:

1. The use of good housekeeping, non-structural BMPs, is well established and practiced, with especially strong emphasis on illegal and illicit discharges of contaminants and the control of erosion during construction.

2. Major facility needs of the stormwater management system would be based on a watershed, or sub-watershed level master planning process. The community would be involved in the process. The process would account for future growth, drainage system needs and other compatible use needs of the community. Impacts, growth trends, costs, maintenance needs, benefits, and other issues and needs would be identified and, when possible, quantified.

3. Use of minimized DCIA elements wherever practicable and possible in residential areas and areas such as parks, golf courses, playgrounds, playing fields, and recreation centers.

4. An extensive use of surface infiltration and flow retardance elements such as grass buffers, swales, porous pavement, and infiltration basins when site geology and site conditions permit.

5. Extensive use of on site or regional extended detention basins, retention ponds and/or wetland basins for all urbanizing areas.

    - Sized to capture a water quality volume and to also help mitigate increases in surface runoff from small events.

    - When the drainage system and public safety requires, provides for a surcharge flood control detention above the water quality capture volume.

6. All high density commercial areas, gasoline stations, other commercial areas subject to surface contamination by chemicals or high concentrations of nutrients, and industrial areas subject to chemical surface contamination be addressed on a site-by-site basis to reduce stormwater runoff flow rates and contaminants to maximum extent practicable. Some of these sites may need special treatment measures for the pollutants being generated on the site such as special media filters, and chemical additives.

   - All runoff from the areas subject to contamination be routed through water quality capture volume basins. These basins may need to be oversized if the pollutants are of major concern for environmental and public health protection.

   - All such water quality capture basins would be occasionally audited for compliance to insure that the needed operation and maintenance is being provided. Also, occasional grab samples of the effluent would be taken and tested by their owners.

Closing Remarks

This chapter discusses many issues that relate to BMPs and what is known about their effectiveness in stormwater management. Much of this discussion is based on a plethora of information that is "supported" by a number of local field investigations designed to test a given BMP's "effectiveness" at the specific site. Still needed is a national approach, similar to NURP, that would systematize a large number of investigation into a cohesive, well controlled, program to learn about various BMP functions, physical mechanisms, biochemistry, and design parameters.

Also needed is a better measure of "effectiveness. The current measure in terms of "percent pollutant removal" has no sound technical basis. This is the case whether the effectiveness is measured in term of constituent load reductions or in terms of reduction in concentrations. Lack of a sound definition can lead to findings that may appear to be inconsistent and non-transferable, when in truth, the differences may not be that large if a better measure of effectiveness is used. Another area of need is improving on the design robustness for various BMPs. Until that is done, expecting a specific performance from any given BMPs is unrealistic. Design robustness should improve as more is learned about what design parameters are most important when selecting, sizing and designing each type of BMP.

Urban stormwater management has to consider the safety and welfare of the citizens living in urban areas. Issues of efficient site drainage, control of nuisances caused by inadequate drainage, hazards posed by large storm events and the floods they create, and cost and benefits received for the expenditure of public dollars have to be considered along with stormwater quality and impact on the receiving water quality, integrity and biology. As a result, sound stormwater management has to address not only runoff impact mitigation associated with urbanization, but also the public and community needs as well

The preceding discussion summarizes the potential usability of BMPs. All of this is based on information in need of enrichment. Nevertheless, it should provide a basis for understanding the current BMP state of-of-practice and state-of-the-art and, accordingly, serve as a guide for planners and engineers.

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